United States Air Force
Scientific Advisory Board

Report on

Academic Audit of AFIT Programs in Systems Engineering

SAB-TR-04-05
December 2004

This report is a product of the United States Air Force Scientific Advisory Board Study Committee on the *Academic Audit of AFIT Programs in Systems Engineering*. All statements, opinions, findings, recommendations and conclusions contained in this report are those of the Study Committee and do not represent the official position of the United States Air Force or the United States Department of Defense.

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Executive Summary

In June 2004, the Secretary of the Air Force requested that the Air Force Scientific Advisory Board (SAB) perform a "Quick Look" audit of the Systems Engineering programs at the Air Force Institute of Technology (AFIT). AFIT has graduated students in the Masters, Certificate, and Intermediate developmental Education programs that are part of the academic offerings in the Center for Systems Engineering (CSE). The purpose of this audit was to assess whether these programs are meeting the needs of the key MAJCOM stakeholders, specifically AFMC, AFSPC and AETC. The Secretary and Chief indicated in their charge that the Air Force must "continue to strengthen and improve this critically important discipline to equip those responsible for the development of weapons systems."

A panel was formed consisting of SAB members from universities and industry, chaired by Dr. Richard Murray, Division Chair (Dean) of Engineering and Applied Science at Caltech. Other members of the panel were Dr. Stephen Cross (head of the Georgia Tech Research Institute, former director of the Systems Engineering Institute [SEI], and former professor at AFIT), Col Cary Fisher (head of engineering at USAFA), Mr. Wally Hoff (former VP at Northrop Grumman), Dr. Ann Karagozian (professor of mechanical and aerospace engineering at UCLA), and Dr. Harold W. Sorenson (professor of systems engineering at UCSD and former executive VP at MITRE).

The panel conducted interviews with representatives from all of the major commands, with a focus on the leaders of the engineering activities within the major systems centers (ASC, ESC, and SMC). Also, the panel met with representatives from SAF/AQ, AFRL, AETC, MITRE, Aerospace Corporation, and other individuals who had substantial interactions with systems engineering in the Air Force. Each of these groups were asked to describe the Air Force needs in Systems Engineering, to describe the role of AFIT in educating Air Force Systems Engineers and to evaluate whether AFIT was on the right track to satisfy that role. In addition, the committee received materials from AFIT and the CSE describing their current programs and met with the leaders of the CSE and the Systems Engineering programs to understand the current status of the program.

The current focus of the MS and IDE programs at AFIT is systems analysis and product systems engineering, with a heavy focus on mathematics and discipline specific courses. The panel felt that, while new courses have been added, the systems engineering offerings at AFIT are not yet as strong as the corresponding programs at major universities. Furthermore, the audience for the academic programs could be further broadened, as their is a major need within the Air Force for officers who have training in Systems Engineering.

Based on the discussions with MAJCOM stakeholders and the audit of the academic program at AFIT, the panel formulated a set of four primary recommendations:

1. AFIT should develop and implement a strategic plan to sustain a systems engineering program focused on Systems Engineering Management (SEM) and Systems of Systems (SoS) that meets the needs of ESC, SMC, ASC and AAC (and other AF organizations) and establish an ongoing mechanism to review this plan annually to ensure it is accomplishing its objectives

2. To reach the broadest possible audience, AFIT should create a Master of Engineering (MEng) degree in Systems Engineering, available to all officers, that can be completed in 12 months and involves hands-on systems engineering experience as part of the degree requirement

3. AFIT should hire or obtain the services of experienced SEM and SoS engineers to teach the majority of required curriculum for AFIT systems engineering degrees and certificate programs

4. The Air Force should establish a mechanism for requiring systems engineering understanding, skills and insights in appropriate AF positions and re-examine the billet coding and assignment of SE officers across the board

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1. Introduction

The Air Force Scientific Advisory Board was asked to perform a "Quick Look" academic audit of the Systems Engineering programs at the Air Force Institute of Technology (AFIT). AFIT has now graduated students in the Masters, Certificate, and Intermediate Developmental Education programs that are part of the academic offerings in the Center for Systems Engineering (CSE). The purpose of this audit was to assess whether these programs are meeting the needs of the key MAJCOM stakeholders, specifically AFMC, AFSPC and AETC.

For the purpose of this report, we define the term *systems engineering* to be the process by which a customer's needs are satisfied through the conceptualization, design, modeling, testing, implementation, and operation of a working system. There are a range of levels of systems engineering, from product systems engineering used for a standalone product or vehicle platform, to design and integration of so-called "systems of systems" (such as an air operations center), to enterprise wide systems engineering that span an entire organization (such as the command and control system for a combat commander). Increasingly, the design of such systems must take into account spiral development and post-operational upgrades, allowing flexibility in the design and operational use of the system over the entire system life cycle.

Successful systems engineers are more generalists than specialists since they are required to work effectively with and between managers and engineers. This fact has not changed over time but the level and breadth of the systems being "engineered" is monotonically increasing. What were once subsystems are now components and what were once systems are now subsystems. Design of commercial communications system hubs or web servers are small parts of large and complex networks. Design of a military air vehicle or a satellite is no longer a "contained" system, because it is functionally part of a group of networked aircraft or a constellation of satellites synergistically performing a needed mission or creating a desired effect. As a result, the function of system engineering is increasingly more essential and, therefore, more challenging.

The breadth of the systems engineer is generally captured through an understanding of processes; ranging from general systems engineering processes to specialized aspects of component design, manufacturing, testing and operations. In essence, many functions of the systems engineering process are themselves processes. Thus, the systems engineering education transcends the normal engineering education by requiring a deep understanding of key technical processes and their supporting methodologies and tools. The processes are most effectively understood through repeated application and the resulting lessons learned. For the purposes of systems engineering education, this knowledge is often captured through case studies, substantial team projects and hands-on experience.

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2. Air Force Needs in Systems Engineering

As a buyer, operator and maintainer of major military systems, the Air Force is critically dependent on effective systems engineering. While there is a clear understanding of the need for systems engineering within the Air Force at all levels, the number of trained systems engineers is far below what is currently required. This has been exacerbated by recent periods in which some of the systems engineering responsibility was given over to contractors, with little or no government oversight. Fortunately, there is a strong shift back to having broad level system engineering done with the Air Force, in part through focus on this issue by senior leadership.

A major difficulty in building (or rebuilding) systems engineering expertise in the Air Force is the need to learn through experience over a large number of years. Very few opportunities are available for such practical training, either as part formal educational program or through carefully chosen job assignments. Thus, while the need for systems engineering is high, the ability to meet that need poses a serious challenge.

A second difficulty in the application of systems engineering expertise in the Air Force is that systems engineering considerations are often missing from program milestones. As one example, effective risk management is often not done within some programs, perhaps because to do so means one admits to having a program risk. Once that admission is made the program manager and his or her staff may believe they will be subjected to endless reviews from on high. Program Managers (PMs) and Program Executive Officers (PEOs) must make systems engineering a key part of their oversight to insure that it is an integral part of the plan for all new programs.

The need for systems engineering in the Air Force will clearly increase in future years as we move toward more complicated systems of systems and enterprise systems (including network centric systems). These more complex systems are often unprecedented in terms of size and scope, hence their requirements cannot be defined *a priori*; they must be evolved. This suggests the need for a process that goes beyond spiral development to a more concurrent approach for evolution of requirements (e.g., development of the operational view using executable versions of a prototype architecture) in parallel with refining that architecture (e.g., realizing the systems view in accordance with some likely *a priori* systems view).

To be a smart buyer, the Air Force needs to have systems engineers who understand systems engineering processes and products. Industry will provide the systems engineers who will actually create and produce the systems that are acquired by the Air Force. Thus, the systems engineers employed by the Air Force must be able to (1) define and articulate the system characteristics/specifications to be provided to a contractor for implementation; (2) assess and evaluate the contractor's system engineering people, processes, their use of the supporting technologies, and their systems engineering performance throughout the lifecycle; and (3) be a competent partner with the contractor to resolve issues and problems.

To meet these needs, the Air Force will need a cadre of civilian and military personnel who have varying levels of systems engineering expertise. We believe that *every* civilian or military engineer involved in acquisition should have some formal exposure to systems engineering and that higher positions within a program—such as chief engineer—should have knowledge, skills and experience at a level consistent with the responsibility of the position. The Air Force must expose a large number people to a top level understanding and awareness of system engineering, whether through short courses, certificate programs, or other mechanisms. Key Air Force officers who are involved in program execution will require an even more thorough understanding that might build on the above courses with additional education and training (and possibly internships), culminating in a certificate or graduate degree.

Data from the DDR&E and other sources indicate that the current situation will worsen as senior engineers reach retirement age during the next five to ten years. While there appears to be no credible estimate of the Air Force needs for systems engineers over the next decade, one must conclude that the requirements are very substantial. For AFIT to respond to this need, there must be a very substantial effort to educate and train a large Air Force audience.

3. AFIT Systems Engineering Program

Background and Context

Historically, Air Force development and acquisition centers were involved with product systems engineering, whether an aircraft, missile, or space satellite system. Even C4ISR systems were generally "stove-piped" and each system was developed as a relatively autonomous entity. The advent of the Internet and the World Wide Web has demonstrated the advantages that can result from the integration and interoperability of legacy systems and this necessitates the broader perspective of enterprise systems engineering. The C4ISR community at the Electronic Systems Center (ESC) at Hanscom AFB has been the most affected but ASC, SMC, and AAC and their systems engineering community must more fully understand and plan for their place in the integrated and interoperable world that is emerging. Thus, the Air Force needs engineers who are educated in a full range of systems engineering processes, methodologies and tools.

The complexity of the integrated and interoperable environment has been induced by several factors to include the global national security environment, the ever-increasing number of legacy and stove-piped systems that must be integrated, and the rapid evolution of information and telecommunication technologies. These factors have led to an increasing emphasis on the use of "architectures" as a context for evolving the system of systems. Architectures provide a structure that can be used to guide the integration, interoperability and development processes. At the enterprise level, architectures serve to define standards and requirements for the integration and interoperation of the system of systems. The description of an architecting process has become a fundamental need for the systems engineer. The DOD Architecture Framework (DOD AF) describes the products of the architecting process.

While a system has a single architecture, the architecture can be described from many perspectives (i.e., "adjective" architectures). For example, an n-tiered, or layered, systems architecture that is seeing widespread application identifies integration challenges involving the (1) presentation, (2) application, (3) information and data, and (4) communication layers. The layers are supported through the use of (5) network and information managers/brokers and the entire system must actively support (6) information assurance and system security. These six elements must be part of the education of the systems engineer. These six elements also provide a basis for establishing technical requirements as part of the overall educational program. Their implementation relies heavily on the methods and tools of the Internet and the World Wide Web.

Support for the systems engineering processes are provided, whenever possible, by an integrated set of models and simulations that range from decision support and cost analysis tools to dynamic models that allow assessment of performance and quality of service requirements. Included in these modeling and simulation tools are those that permit the consideration of executable architectures to provide assessments of behavior, function, and performance. The AFIT graduate program must present a detailed description, with case studies and examples, of the modeling, simulation and analysis (MS&A) process. Further, some introduction to key tools for the varied elements of MS&A with discussion of the strengths and limitations of the tools is necessary.

It has become increasingly clear that the complexity of the systems engineering environment and the associated architectures requires the use of tools that assist in the navigation and understanding of the system being engineered. These tools must allow for "what if" questions to be answered in ways that communicate to the levels of management that are involved and interested in the development. Human-system interface tools, including visualization and graphical displays, constitute an increasingly valuable part of the systems engineers' toolkit. These tools augment the MS&A tools that play such an important

role in the implementation of the systems engineering process and constitute important elements of the presentation layer of the systems architecture.

US Educational Programs in Systems Engineering

A large number of programs in systems engineering have been developed over the past decade to address the increasing educational need for well-trained systems engineers. These programs range from certificate programs, to Master of Engineering (MEng) degrees that offer a practically oriented graduate education, to traditional BS, MS, PhD programs. Broadly speaking, these programs can be divided into five general classes (described in more detail in Appendix F):
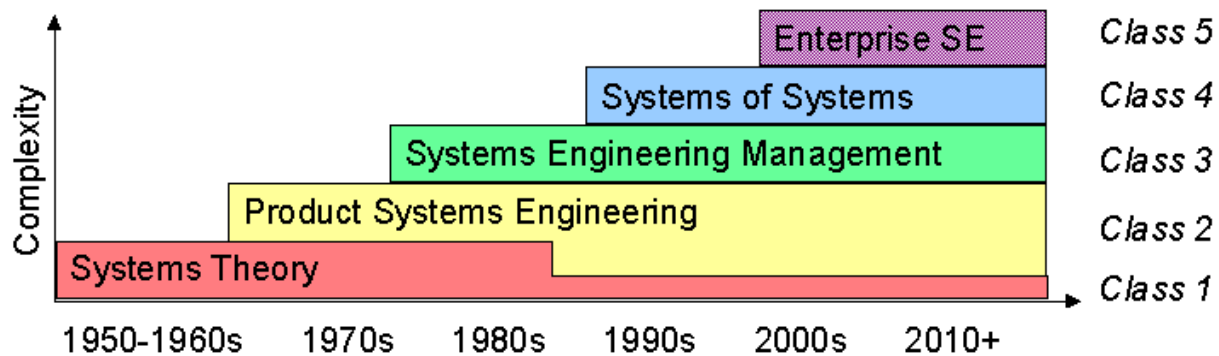
- Class 1 – Systems Programs: There are several programs that are the children of the "systems theory" programs that emerged in the 1950s and 60s. The core of these programs has its roots in control systems, communication systems and their application to the guidance and navigation problems of the time. These programs cover the core topic materials that include complementary subjects such as optimal control, stochastic processes, decision analysis and other elements of applied mathematics.
- Class 2 – Product Systems Engineering: These programs trace their roots to the life-cycle considerations of product development, fielding, and sustainment. They are characterized by offerings that are focused on the systems engineering processes, methodologies and tools that support the process. Topics common to this engineering field of study include requirements analysis, trade-off and decision analyses, design specifications, verification and validation, and life cycle "-ilities" (e.g., reliability. producibility, sustainability, etc). They are often housed in traditional engineering departments with an emphasis that is frequently linked to the needs of industries and companies in the school's local area.
- Class 3 – Systems Engineering Management: As part of the Product Systems Engineering program, but sometimes separate from it to a major extent, there are programs that emphasize program and project management. These programs emphasize the managerial tools that must be learned. The topics include cost analyses, risk management, project control, leadership and team building, and other related subjects.
- Class 4 – System of Systems Engineering: A small number of programs are evolving to include material that deals with the problems engendered by the Internet and network-centric operations. These programs introduce "architectures" and emphasize the "integration" of legacy and new systems. These programs continue to deal with the processes, methods and tools of Classes 2 and 3, above. But they also supplement the offerings with material that recognizes the new challenges of these systems engineering problems, relying heavily on computer and information system

concepts and methods. Included in these programs are courses dealing with human-system interfaces, large-scale modeling and simulation for decision support, and performance analyses of integrated systems.

- Class 5 – Enterprise Systems Engineering: Class 4 is extended in a very few programs to deal with the need for the enterprise-wide information and knowledge system to deal with the complexity caused by the dimensionality of the integration problem and the need for the enterprise to work seamlessly across previously autonomous business and support organizations. These programs add more emphases on corporate management topics such as mission descriptions, strategic planning, investment planning, marketing and customer support, business operations, and competitive analyses and the assessment of product success. In most cases, this class of programs involves some degree of cooperation between and involvement of engineering schools and management schools.

The boundaries between these five classes of systems engineering are not precise and programs may have elements of each. Most programs emphasize either class 1 or class 2 and/or 3. The latter two classes often appear jointly as specialty tracks to meet student interests. Class 1 introduces a much greater emphasis on the use of applied mathematics than any other classes. A more detailed description is provided in Appendix F.

The Systems Engineering Curriculum at AFIT

AFIT currently offers three degree programs in Systems Engineering: Graduate Systems Engineering (Masters degree), Intermediate Developmental Education (IDE), and Systems Engineering Certificate. These programs are all based on four core courses, each of which gives 4 quarter hours of credit:

- systems engineering management (SENG 510)
- systems engineering design (SENG 520)
- introduction to software engineering (CSCE 593)
- system architecture (SENG 640).

Descriptions of these courses, and others offered as part of the Systems Engineering program are given in Appendix G.

As described in the 2004-05 course catalog, the Graduate Systems Engineering (GSE) program is an ABET accredited resident program at AFIT leading to a Master of Science (MS) degree in Systems Engineering. It is normally a six quarter (18 month) program, with students normally entering in September and graduating in March. The Systems Engineering program provides an introductory technical foundation in systems architecture, analysis and design as well as specialization within a traditional engineering discipline. Students with non-technical backgrounds may be admitted into the program, but may require preparatory math and other courses in addition to the Systems Engineering program requirements. The program culminates with an individual thesis or group design project typical of a defense system project. In the design study, the students apply their individual technical expertise, exercise their system design skills, and experience the group dynamics of a team design effort while solving a defense system problem. To date, the MS program has graduated 1 officer and 8 students (6 military, 2 civilian) are currently enrolled.

The IDE Graduate Systems Engineering (IGSE) program is also an ABET accredited resident program leading to an MS degree with a concentration in Systems Engineering. The IGSE program is identical to the masters program in Systems Engineering with the exception that a thesis is not required; however, a smaller group project (4-8 quarter hours) is required as part of the IGSE program. This program is

nominally a four quarter (12 month) program, with students entering in September and graduating in the following September. Officers must be selected to participate in this program and are typically more senior than students in the MS program (Majors versus Lieutenants and Captains). To date, the IDE program has graduated 19 students and currently has 35 students enrolled.

The Systems Engineering Graduate Certificate Program is a subset of AFIT's Systems Engineering Master's program. It is tailored to provide practicing engineers with core Systems Engineering knowledge. This program consists of the four core Systems Engineering courses and a capstone project. These courses are part of the Systems Engineering Master's degree program and may also be used as minor concentration in another AFIT degree program. To date, 10 students have received certificates and 15 are currently enrolled. Of those currently enrolled, 5 are receiving their coursework through the partnership with the University of New Mexico.

The primary focus of the MS and IDE programs is systems analysis and product systems engineering (class 1 and class 2), with a heavy focus on mathematics and discipline specific courses. This reflects a view of systems engineering that is very academic in nature and does not take into account the growing needs of the Air Force in systems engineering management (class 3), systems of systems engineering (class 4) and enterprise systems engineering (class 5).

While new courses have been added (e.g., the four core courses), the systems engineering offerings at AFIT are not yet as strong as the corresponding programs at major universities (see Appendix F for an analysis of other university programs). In particular, there is little attention at AFIT directed toward Class 4 or Class 5 types of systems engineering problems beyond the two introductory classes (SENG 510 and SENG 640). In addition, the program does not seem to make substantial use of the materials offered by the Systems and Engineering Management Department. Further, the AFIT program does not appear to focus on the domain of the warfighter. This probably occurs in the projects, but it does not approach the needs through existing courses, as is done at the Naval Postgraduate School. This focus seems to be one of the advantages that AFIT can offer relative to all other academic systems engineering programs at civilian universities.

The program is new and allowances must be made for this reality. The development of a strong program that will meet the Air Force needs of the future will take time. Some appropriate steps have been taken and the panel was informed of their plans to introduce additional elements. These additions need to be supported, but the review of other strong programs causes a concern that the proposed journey will not reach the goal, not for lack of desire, but from lack of a long-term vision and the resources to achieve the vision.

Moving Forward

The Center for Systems Engineering and AFIT have been charged to develop a systems engineering capability that meets the future needs of the Air Force. To do so, this need must be clearly articulated and a strategy must be developed to meet the need. As we have already noted, the requirement is currently ill defined, a situation that is commonly faced in trying to accomplish enterprise systems engineering. A proposed solution path is captured in the DOD Architecture Framework products where the Operational View requires an understanding of goals, objectives, and missions of the enterprise. The model would appear to apply to the problem faced by CSE and AFIT.

Accepting that a quantitative assessment of the Air Force needs for systems engineers is not available and may be impossible to get, it seems incumbent on the CSE to define goals and objectives for the activity. We believe that a sound strategy should include the following elements:

- *The academic structure of the envisioned graduate program.* Thought needs to be given to the structure of an integrated program that truly meets the systems engineering needs of the Air Force. This structure will include multiple programs and may include multiple partners in order to meet the differing needs of Air Force officers and civilians.

- *The involvement of seasoned systems engineers as strategic planners and faculty in the future offerings of the program.* A sound systems engineering program requires some number of faculty who have actually been involved in the systems engineering challenges of significant development programs. Experienced systems engineers need to be identified and brought into the program development and the course offerings. The greatest need is to involve competent and articulate individuals who can shape the enterprise or system of systems engineering aspect of the program.

- *The needs of ASC, AAC, ESC and SMC (and other AF organizations).* As the program is tasked to respond to the needs of the Air Force, the systems engineering program must deal with the different needs of C4ISR and space systems. The strategic planning process must understand the needs and create the program to accommodate them. The questions are complicated because they must involve both the Aerospace and MITRE Corporations and their systems engineering role at these two Centers.

- *The number of graduate system engineering degrees to be awarded annually in steady state.* This should take into account the number of students coming to AFIT as well as certificates or degrees that are offered through partnerships with other universities. As an example, alliances with the University of Dayton and Wright State University appear to offer real promise as vehicles to reach a bigger student audience and to leverage capabilities not resident at AFIT to strengthen the program. Dr. Levis has proposed a particularly interesting concept. His proposal for "An Alternative Model for Advanced Degrees" merits strong consideration as part of defining the strategy for increasing the number of systems engineering graduates available to the Air Force. (See Appendix H for the complete text of the proposal.)

- *Linkage with the US Air Force Academy undergraduate systems engineering program.* There needs to be continued planning for a meaningful relationship between the USAFA and AFIT. The opportunity for synergies, including distance-learning opportunities to enrich the experience of both undergraduate and graduate students needs to be explored.

- *The next and future assignments of graduates.* Within the context of the Air Force personnel system, the program should seek to place its graduates in programs where their knowledge of systems engineering can best be used.

- *Additional program resource requirements.* As the strategic view and plan is determined, AFIT needs to identify the additional resources that are required in terms of new faculty, additional laboratory capabilities, systems engineering tools useful in increasing the reality of systems engineering team projects, and resources needed to engage in substantial relationships with other organizations. The strategic plan should provide the Air Force leadership with a realistic assessment of the program that can realistically be supported with the current resources and the cost of incremental steps toward the strategic vision for the operation of the CSE and the program provided by AFIT.

In addition to these elements of the AFIT systems engineering plan, it will also be necessary for the Air Force to address issues as part of its strategy for improving the application of systems engineering. We believe that the following elements must be addressed and appropriately reflected in an AFIT/CSE strategy:

- *Providing systems engineering assistance and academic opportunities to the Air Force Research Laboratory.* The Air Force has long talked about the difficulties of transitioning AFRL-supported

technologies to development and ultimately to fielded capabilities and systems. A strategic view of the CSE and AFIT responsibility must consider ways for interacting and contributing through informed systems engineering to the value added by the AFRL contributions. This certainly can contribute to a long-standing Air Force need.

- *Ensuring that program/project managers are knowledgeable and responsive to the values of sound systems engineering*. Systems engineers are not "masters" of their own fate. The resources of a Program Office involve decisions that can limit or eliminate the ability of the systems engineers to accomplish their responsibilities in an effective manner. Thus, a significant part of the education process needs to be directed toward the program management side of the business. The need for PMs/PEOs to provide oversight of the systems engineering implementation within the programs in their portfolio seems a necessary check and balance for the system. The strategy for broadening the awareness and appreciation of the systems engineering role and responsibilities needs to be articulated and worked within the broad acquisition community.

This list is not meant to be all-inclusive, but indicates the elements that we believe should be addressed by the AFIT/CSE strategic plan if it is to respond to the needs to the needs of the Air Force.

4. Recommendations

Based on our discussions with MAJCOM stakeholders and our audit of the academic program at AFIT, we believe that there are three sets of recommendations that should be implemented: strategic, enterprise, and tactical. Our strategic recommendations are those for which AFIT has the primary responsibility and focus on the long-term needs of the academic program. Our enterprise recommendations are those that affect AFIT's prospects for success, but are not directly within the control of AFIT or the CSE and hence must be implemented by the Air Force leadership. Finally, our tactical recommendations represent a few near term actions that could be taken by the CSE.

Recommendations for AFIT

1. **Develop and implement a strategic plan to sustain a systems engineering program focused on Systems Engineering Management (SEM) and Systems of Systems (SoS) that meets the needs of ESC, SMC, ASC and AAC (and other AF organizations) and establish an ongoing mechanism to review this plan annually to ensure it is accomplishing its objectives.** The current systems engineering program, while a good start, does not appear to be sufficiently focused on the long term needs of the Air Force. The strategic plan should address the specific elements identified in the previous section and should focus on systems engineering management (class 3) and systems of systems engineering (class 4), rather than the current emphasis on traditional systems analysis (class 1). If the program is housed within a specific department, it must be done in a manner that does not limit enrollment in the program to any specific engineering discipline, but rather focuses on systems engineering processes that are key to development of systems of systems. To oversee this program, Air University's Board of Visitors should establish a standing subcommittee that includes well-respected members of the SE committee and that reviews the implementation of the strategic plan on an annual basis. In developing and implementing their strategic plan, AFIT needs to talk more frequently with its "customers" (e.g., AFMC/EN, ASC/EN, ESC/EN, SMC/AX) to verify that their educational needs are being met and this should be an explicit part of the annual evaluation of the academic program.

2. **To reach the broadest possible audience, create a Master of Engineering (MEng) degree in Systems Engineering, available to all officers, that can be completed in 12 months and involves hands-on systems engineering experience as part of the degree requirement.** While officially the MS program only requires 4 quarters to complete, in practice it has been designed to take 18 months (as described in the catalog entry). The program is longer than needed for many officers and often focuses on a research project instead of a hands-on project. The current IDE program, with a required project, should be opened up to all officers and expanded in size to allow for higher enrollment. The use of MEng degree rather than an MS should reflect the focus on the practical rather than research aspects of the degree. The curricula for the MEng should focus primarily on systems engineering (rather than discipline-specific topics) and should specifically address understanding and skills required to meet Air Force needs as described in recommendation 4. The CSE may wish to consider including an internship as a possible substitute for a project and also consider the viability of offering the course remotely rather than only at AFIT, as described in Alex Levis' proposal "An Alternative Model for Advanced Degrees" (see Appendix H).

3. **Hire or obtain the services of experienced SEM and SoS systems engineers to teach the majority of required curriculum for AFIT systems engineering degrees and certificate programs.** Most of the current instructors for the SE courses at AFIT do not have substantial experience working as a systems engineer in major systems programs. Since systems engineering

is something in which experience plays a major role, it is essential that courses be taught be individuals who have had such experience, with a priority given to instructors with experience on large DoD programs. One possible mechanism to hire such individuals is to work with AFRL and the Wright Brothers Institute (WBI) to recruit a chair or eminent scholar in system engineering. Towards that end, WBI could broker contract relationships with qualified universities that would provide visiting faculty to AFIT who would also work on AFRL research projects. A related idea is to institute an executive in residence program to recruit highly talented system engineers from industry, not just the defense industry, or former senior government officials. A part-time or on-loan arrangement with ASC may be a good way to get instructors with fresh information to teach one course per semester (or more if ASC will loan the officers to AFIT for a quarter or more). Another way of providing insight and lessons learned in systems engineering on Air Force programs is to invite guest lecturers from industry.

Recommendations for the Air Force

4. **Establish a mechanism for requiring systems engineering understanding, skills and insights in appropriate AF positions and re-examine the billet coding and assignment of SE officers across the board.**   Require the chief engineer for every PEO to be a systems engineering graduate, at least at the level of a certificate. Require each PEO to hold annual planning workshops at CSE with his/her PMs and chief engineers to assess architecture, risks, lessons, learned etc. An overhaul of CSE is not going to meet the needs of the Air Force unless an overhaul of AFPC's SE officer assignment processes accompanies it. Management of USAF Weapons School graduates may provide a good example. SE officers may need an AFSC prefix to make this work, like the "W" prefix for Weapons School grads. (S61S3A or S62E3, for example).

5. **Work with AFRL to develop material for case studies and explore the potential of AFRL internships for AFIT students.** Currently, AFRL employees attend AFIT to obtain advanced degrees and they often use their work assignments as the basis for projects and/or a thesis. Expanding to the apprentice level offers the potential of getting additional help on internal projects but it also provides a means for recruiting officers for future assignment to AFRL. From the viewpoint of AFIT, this provides a way to blend practical experience with formal education without the faculty burden of overseeing the projects.

Recommendations for the CSE

6. **Create a top 10 list for the PEO: What top ten system engineering questions should every PEO ask every PM before critical milestones?** While this risks trivializing system engineering, if done correctly it is a fast way to communicate and make real a focus on system engineering in every program. Note that former Air Force PEO Claude Bolton, now the Army Assistant Secretary for Acquisition, Technology, and Logistics does something very similar for the acquisition of software intensive systems. Review systems engineering processes established by industry to take advantage of the lessons learned.

7. **Institute an "independent review in advance" service for newly assigned PMs and their staffs.** A variant might be to stage mock source selections tailored to the solicitation planned by a PM to help train the PM's staff. These would illustrate the application of good system engineering within the context of what a government engineer is required to do. Or hold a "year in the life" of a program workshop tailored to the needs of the PM and her staff. All of this assumes a good case library.

Appendix A: Secretary of the Air Force Direction

SECRETARY OF THE AIR FORCE
WASHINGTON

JUN 30 2004

MEMORANDUM FOR CHAIRMAN, AIR FORCE SCIENTIFIC ADVISORY BOARD

SUBJECT: Academic Audit of Center for Systems Engineering (CSE)

General Jumper and I would like the Air Force Scientific Advisory Board (SAB) to perform a "Quick Look" audit of the academic programs of the Air Force Institute of Technology's CSE.

The CSE was established in February 2003 and to date we have graduated students from each of its academic programs. We must continue to strengthen and improve this critically important discipline to equip those responsible for the development of weapon systems.

The audit should focus on the academic offerings for the Systems Engineering Masters, Certificate and Intermediate Developmental Education programs. Specifically, we would like to know if these programs are meeting the needs of our key MAJCOM stakeholders: AFMC, AFSPC, and AETC.

Please add this audit to the SAB efforts performed during the next study cycle and brief General Jumper and I on your findings by 15 Dec 04.

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Appendix B: Study Members

<u>Study Members</u>
Prof. Richard M. Murray (chair)
Dr. Stephan E. Cross
Col Cary A. Fisher
Mr. Wallace J. Hoff
Prof. Ann R. Karagozian
Dr. Harold W. Sorenson

<u>Study Management</u>
Maj Christopher N. Berg – Study Project Manager
Mr. Justin A. Waters – Study Technical Editor

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Appendix C: Visits and Contacts

Headquarters Air Force
Air Force Chief Scientist
Assistant Secretary of the Air Force for Acquisition

Air Force Major Commands
Air Education and Training Command
- Air University

Air Force Materiel Command

Air Force System Developers
Aeronautical Systems Center
- Engineering Directorate

Air Force Research Laboratory
- Chief Technologist

Electronic Systems Center (MITRE)
Space and Missile Systems Center
- Systems Acquisitions Directorate

Other Air Force Agencies
Air Force Institute of Technology
- Center for Systems Engineering
- Department of Aeronautics & Astronautics

Department of Defense Agencies
National Reconnaissance Office

Industry
The Aerospace Corporation

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Appendix D: Acronyms and Abbreviations

4TYY	Educational Code for Systems Engineering Masters Degree Program at AFIT
AAC	Air Armament Center
ABET	Accreditation Board for Engineering and Technology
AEFs	Air and Space Expeditionary Forces
AETC	Air Education and Training Command
AF	Air Force
AF/ST	Air Force Chief Scientist
AFB	Air Force Base
AFIADL	Air Force Institute of Advanced Distance Learning
AFIT	Air Force Institute of Technology
AFMC	Air Force Materiel Command
AFMC/EN	Air Force Materiel Command, Directorate of Engineering and Technical Management
AFPC	Air Force Personnel Center
AFRL	Air Force Research Laboratory
AFRL/HE	Air Force Research Laboratory Human Effectiveness Directorate
AFSC	Air Force Specialty Code
AFSPC	Air Force Space Command
AMGT	Acquisition Management
ASC	Aeronautical Systems Center
ASC/EN	Aeronautical Systems Center, Engineering Directorate
BGen	Brigader General
BS	Bachelor of Science
C2	Command and Control
C4ISR	Command, Control, Communications, and Computers, Intelligence, Surveillance, and Reconnaissance
CSCE	Computer Science and Computer Engineering
CSE	Center for Systems Engineering
DDR&E	Direct or, of Defense Research and Engineering
DOD	Department of Defense
DOD AF	Department of Defense Architectural Framework
DP	Director of Personnel
EENG	Electrical Engineering
ENVR	Environmental Managment or Engineering
ESC	Electronic Systems Center
ESC/EN	Electronic Systems Center, Engineering Directorate
GSE	Graduate Systems Engineering
IDE	Intermediate Developmental Education

IGSE	IDE Graduate Systems Engineering
IMGT	Information Management
INCOSE	International Council for Systems Engineering
LQG	Linear Quadratic Gaussian optimal control theory
MAJCOM	(Air Force) Major Commands
MECH	Mechanical Engineering
MEng	Master of Engineering
MGen	Major General
MIT	Massachusetts Institute of Technology
MS	Master of Science
MS&A	modeling, simulation and analysis
NPS	Naval Postgraduate School
OO	Objected Oriented
OPER	Operations Research
PCS	Permanent Change of Station
PEO	Program Executive Officer
PhD	Doctor of Philosophy
PM	Program Manager
PME	Professional Military Education
Prereq	Prerequisite
QMGT	Quality Management
RAM	Reliability and Availability Modeling
SA	Structured Analysis
SAB	(Air Force) Scientific Advisory Board
SE	Systems Engineering
SEC	Graduate Certificate in Systems Engineering
SEM	Systems Engineering Management
SENG	Systems Engineering
SMC	Space and Missile Systems Center
SMC/AX	Space and Missile Systems Center, Directorate of Systems Acquisition
SoS	Systems of Systems
STAT	Probability and Statistics
TDY	Temporary Duty
UML	Unified Modeling Language
USAF	United States Air Force
USC	University of Southern California
WBI	Wright Brothers Institute

Appendix E: Initial Distribution

Air Force Leadership
Secretary of the Air Force
Chief of Staff of the Air Force
Under Secretary of the Air Force
Vice Chief of Staff of the Air Force

Air Force Secretariat
Air Force Chief Information Officer
Assistant Secretary of the Air Force for Acquisition
- Directorate of Science, Technology, and Engineering

Air Staff
Assistant Vice Chief of Staff of the Air Force
Director of the Air National Guard
Chief of Air Force Reserve
Scientific Advisory Board Military Director
Chief Scientist of the Air Force
Deputy Chief of Staff of the Air Force for War Fighting Integration
Deputy Chief of Staff of the Air Force for Air and Space Operations
Deputy Chief of Staff of the Air Force for Plans and Programs
Deputy Chief of Staff of the Air Force for Personnel

Air Force Major Commands
Air Combat Command
Air Education & Training Command
- Air University
Air Force Materiel Command
Air Force Space Command
- Directorate of Engineering and Technical Management
Air Force Special Operations Command
Air Mobility Command
Pacific Air Forces
U.S. Air Forces Europe
Air Force Reserve Command

Other Air Force Elements
Aeronautical Systems Center
- Engineering Directorate
Air Force Institute of Technology
- Center for Systems Engineering
- Department of Aeronautics & Astronautics
Air Force Personnel Center
Air Force Research Laboratory
- Chief Technologist
- Human Effectiveness Directorate
Electronic Systems Center

- Engineering Directorate

Space and Missile Systems Center

- Directorate of Systems Acquisition

United States Air Force Academy

Office of the Secretary of Defense
Under Secretary of Defense for Acquisition, Technology and Logistics
Under Secretary of Defense for Personnel and Readiness

Department of Defense Agencies
National Reconnaissance Office

Executive Office of the President
National Security Council

Advisory Boards
Army Science Board
Defense Policy Board
Defense Science Board
Naval Research and Advisory Committee
Naval Studies Board

Industry
The Aerospace Corporation

Appendix F: Summary Review of University Programs in Systems Engineering

The intent of this summary is to put the AFIT Systems Engineering program into context with the large number of programs that exist at a variety of universities around the world. The International Council for Systems Engineering (INCOSE) has compiled the source of the most complete directory of relevant programs. A copy of the Directory is included as an Appendix I of this report. A review of these programs emphasizes the assertion that "systems engineering" comes in many "flavors".

Given the variety of different academic thrusts and emphases, a detailed summary requires an effort that exceeds the needs of this audit of the AFIT program. Instead, it seems more realistic to define a structure that can be used to distinguish among programs and will permit a description of the role being assumed by the AFIT Systems Engineering program.

Program thrusts:

1. Systems Programs: There are several programs that are the children of the "systems theory" programs that emerged in the 1950s and 1960s. The core of these programs has its roots in control systems, communication systems and their application, among others, to guidance and navigation problems of the time. These programs cover the core topic materials that included complementary subjects such as optimal control, stochastic processes, decision analysis and other elements of applied mathematics. Several of the programs identified in the INCOSE Directory have their roots in these academic fields of study. The AFIT program, as is highlighted below, exhibits many of these characteristics.

   Key terms: systems dynamics, control systems, optimal systems, communication systems, stochastic systems, estimation and filtering.

2. "Product" Systems Engineering: There are many programs whose roots trace to the lifecycle considerations of product development, fielding, and sustainment. These programs are characterized by offerings that are focused on the systems engineering process and the methodologies and tools that support the process. Topics common to this engineering field of study include requirements analysis, trade-off and decision analyses, design specifications, verification and validation, and life cycle "-ilities" (e.g., reliability. producibility, sustainability...). From a review of this type of program, one finds them housed, often, in Engineering Departments with the names "Industrial", "Manufacturing", "Civil ", "Environmental", and "Aeronautical" in their title. One can conclude that the departmental emphasis is closely linked to the needs of industries and companies in the school's locale.

   Key terms: requirements, decision analysis, verification and verification, system test, sustainability, life cycle

3. Systems Engineering Management: As part of the "Product" Systems Engineering program, but sometimes separate from it to a major extent, there are programs that emphasize program and project management. These programs emphasize the managerial tools that must be learned. The topics include cost analyses, risk management, project control, leadership and team building, and other related subjects.

   Key terms: project management, risk management, cost analysis, team building, program control methods

4. <u>"System" Of Systems Engineering</u>: Some, but not many, programs are evolving to include material that deals with the problems engendered by the Internet and network-centric operations. These programs introduce "architectures" and emphasize the "integration" of legacy and new systems. These programs continue to deal with the processes, methods, and tools of Topics 2 and 3, above. But they also supplement the offerings with material that recognizes the new challenges of these systems engineering problems. These materials rely heavily on computer and information system concepts and methods. Included in these programs are courses dealing with human-system interfaces, large scale modeling and simulation for decision support and for logic, behavior, and performance analyses of integrated systems.

   Key terms: systems architectures, integration, human-system interfaces, software integration frameworks, structured analysis, objects and components, Unified Modeling Language (UML)

5. <u>"Enterprise" Systems Engineering</u>: Topic 4 is extended in a very few programs to deal with the need for the enterprise-wide information and knowledge system to deal with the complexity caused by the dimensionality of the integration problem and the need for the enterprise to work seamlessly across previously autonomous business and support organizations. These programs add more emphases on corporate management topics such as mission descriptions, strategic planning, investment planning, marketing and customer support, business operations, and competitive analyses and the assessment of product success. In most cases, this class of program involves some degree of cooperation and involvement between Engineering Schools and Management Schools.

   Key terms: enterprises; missions and environment, strategic planning, investment planning, interoperability, complexity of large scale systems, building collaborative teams, lessons learned and patterns, n-tiered system architectures

The boundaries between these five classes ("flavors") of systems engineering are not precise and programs may have elements of each. But most programs emphasize Class 1 or Class 2 and/or Class 3. The latter two classes often appear jointly as specialty tracks to meet student interests. Class 1 introduces a much greater emphasis on the used of applied mathematics than any of the other classes. In these programs, processes and heuristics are fundamental methodologies with applied mathematics used where appropriate.

Degree Offerings

Universities offer a full range of recognized programs. The most common is a Master of Science degree that can be completed by one year of full-time study. But some universities have MS degrees that require 1½ years or more of full-time study to complete. In almost every program, there are requirements for the completion of a large program of courses that deal with topics related directly to the Systems Engineering field of study (e.g., ten of twelve courses, including selections among selected electives). In addition, almost all of these programs require the completion of a substantial systems engineering project. There are also "dual track" offerings that can produce two Masters Degrees (e.g., one in Engineering and one in Business) and take two years of full-time study to complete. A surprising number of universities offer B.S degrees in Systems Engineering and many offer a PhD in Systems Engineering (or related titles). There are many Certificate programs in Systems Engineering where a Certificate requires ¼ to ½ of the number of courses for an MS degree. The Certificate programs often include a project as part of the requirements. Further, there are a large variety of short courses that deal with some aspect of Systems Engineering. Finally, as a reflection of the times, there are many "distance learning" programs that allow program participation for a wider range of students than was formerly true.

System Engineering Application Offerings

Projects are typically drawn from applications that are central to the interests of the department that offers the degree program. As stated earlier, many of the programs are part of departments with the terms Industrial, Manufacturing, Civil, Environmental, or Aeronautical in their title. In the context of the AFIT program, the Meyer Institute for Systems Engineering at the Naval Postgraduate School (NPS) (See http://ocl.nps.navy.mil/msse/), offers several courses related to the warfighter and military domains of interest.

Representative Programs for Each of the Five Classes

1. The Department of Management Systems and Engineering (MS and E) at Stanford University offers an interesting set of programs that cover the range of topics from Class 1 to 5. The central theme appears to be the extension of applied mathematics to systems problems (i.e., deep roots in Class 1). (See http://www.stanford.edu/dept/MSandE/)

2. Programs at Johns Hopkins University (See http://ptesrv.apl.jhu.edu/04_05_catalog/se.html), George Washington University (See http://www.emse.gwu.edu/emse/program/), Cornell University (See http://www.systemseng.cornell.edu/) and the University of Maryland (See http://www.isr.umd.edu/ISR/education/MSSE/) offer examples of programs that can be identified as Class 2 and 3, historically, but are now evolving to include Class 4 considerations.

3. The program at USC (See http://www.usc.edu/dept/ise/), which is part of the Industrial and Systems Engineering Department, has its roots in the systems engineering of satellite systems, and has a significant focus on the use of architectures as mechanism for providing a pervasive structure for the development of complicated systems.

4. The programs at George Mason University (See http://www.gmu.edu/departments/seor/). Stevens Institute of Technology (See http://www.soe.stevens.edu/seem/), and the Engineering Systems Division at MIT (See http://esd.mit.edu/) appear to be leaders in the movement into Class 4 or Class 5 types of Systems Engineering programs.

5. The Carey School of Business at Arizona State University offers interesting programs in the Management of Information and Knowledge. The emphasis here appears to be more closely linked to Class 5 than most programs in the Directory. (See http://wpcarey.asu.edu/mba/ft_msim/msim_info.cfm). It is interesting that this program is housed in the Business School.

There are, as indicated in Appendix I, a large number of programs that could be cited. In the interests of brevity, there has been no attempt to refer to all of them. The reader is encouraged to explore the web sites that are identified.

The AFIT Graduate Program in Systems Engineering: A Context

In Appendix J, a copy of a sample graduate program, taken from the AFIT web site is presented. While there are unstated electives, the implication seems to be that the program is heavily focused on the Class 1 types of education elements (i.e., systems and dynamics). While recognizing this is only a sample and other alternatives are possible, it seems important that this is the only sample displayed at the web site. Also, it makes clear that the architecting course, while a critical addition to the program, does not

apparently feed into any other course. Further, there seems to be minimal connection to the challenges of the systems of systems environment (i.e., Class 4).

In another direction, if one examines the offerings of the Systems and Engineering Management Department at AFIT (See http://en.afit.edu/env/), they seem very relevant to the overall needs of the SE program. In particular, the programs offered by the SEM Department, among others, include:

1. Cost Analysis
2. Research and Development Management
3. Information Resource/Systems Management

The current AFIT program seems too focused on the systems thinking of the past (i.e., Class 1). While courses have been added (e.g., the four Core courses), the offerings when compared with any of the programs at major universities appear very weak. There is little attention directed toward Class 4 or Class 5 types of systems engineering problems. In addition, the program does not seem to make appropriate use of the materials offered by the Systems and Engineering Management Department. Further, the AFIT program does not appear to focus on the domain of the warfighter. This probably occurs in the projects, but it does not approach the needs through existing courses as is done at the Naval Postgraduate School. This focus seems to be one of the advantages that AFIT can offer relative to all other academic systems engineering programs at civilian universities.

The program is new and allowances must be made for this reality. The development of a strong program that will meet the Air Force needs of the future will take time. Some appropriate steps have been taken and the SAB audit group was informed of their plans to introduce additional elements. These additions need to be supported. But the review of other strong programs causes a concern that the proposed journey will not reach the goal, not for lack of desire, but from lack of a long-term vision and the resources to achieve the vision.

Appendix G: AFIT Systems Engineering Course Listings

SENG 505 - Instrumentation and Measurement Lab
An introduction to instrumentation and procedures used in measurement systems. Includes measurement of static and dynamic response of solids, fluids, and thermal processes. Includes a group project specifically aimed at the student's thesis area. Prereq: None

SENG 510 - Systems Engineering Process and Management
This is a graduate course primarily intended for the Master of Science program in Systems Engineering. It will provide an overview of the Systems Engineering process, and selected topics from Systems Engineering Management. Topics include a model based-approach to key systems engineering design activities, process modeling, requirements analysis and functional allocation, trade-off analysis, and management of cost, schedule and risk. As part of the Systems Engineering core, it is complemented by SENG 520, Systems Engineering Design, SENG 540, Systems Architecture, and CSCE 593, Introduction to Software Engineering. Prereq: None

SENG 516 - Introduction to Instrumentation
An introduction to instruments and systems with an emphasis toward experimental research. Topics include: instrument theory; static characteristics and error analysis; dynamic characteristics and instrument response to steady, periodic, transient and random inputs; impedance, transducer and read-out concepts, modeling of instruments and systems; analog and digital filtering, operational amplifiers, digital data acquisition, introduction to Fast Fourier Transform. Prereq: Undergraduate circuit theory

SENG 520 - Systems Engineering Design
This course provides a broad introduction to the structured approach necessary for the design of complex systems. The formulation of systems problems and the approach to their solution will be emphasized. Basic mathematical techniques available to the systems engineer are presented. The design process will be illustrated through the review of past design efforts, and the application to a problem of current interest. Prereq: None

SENG 525 - Linear Systems Analysis
This course covers the underlying theory of linear time invariant and time varying dynamic systems. The modeling of engineering systems, including mechanical, electrical, fluid, and thermal systems is covered. Analysis techniques include classical analysis in the continuous time, discrete time, frequency domain, and modern state space techniques for linear systems. Prereq: None

SENG 530 - Introduction to Space Programs and Operations
This course examines the history and current status of military space operations. Topics include the history of space flight, the relationships between military and civil space programs, space law, US space policy, military space missions, US military space organizations, and non-US space programs. Introduction to standard space mission analysis software. Prereq: Permission of Instructor

SENG 535 – Military Space Systems and Applications
This course is designed to provide the student with a picture of worldwide space activities, with an emphasis on military space operations. Seminars will include classified presentations by intelligence analysts. Subjects covered will include operational and technical aspects of US and foreign space systems and related topics of DOD interest. Prereq: Permission of Instructor

SENG 563 - Terminal Effects and Delivery of Conventional Weapons
This course provides the analytical basis for computing delivery trajectories and terminal effects of conventional weapons. It covers such topics as vacuum trajectories and atmospheric trajectories, powered trajectories, and projectile stability. Terminal effects are quantified and related to potential targets and their damage criteria. The following terminal effects topics are studied in some detail: chemical explosives and blast waves, guns and projectiles, fragmentation warheads, projectile impact, target hardness, armor penetration, shaped charge weapons, and explosively formed fragments. Prereq: Undergraduate Dynamics

SENG 564 - Conventional Weapons Effects
This course provides a basis of understanding in the analysis of effectiveness of conventional weapons against air and ground targets. It includes a study of several conventional damage mechanisms, conventional explosives and projectile and fragment trajectories. Weapons effects and target survivability are discussed. Types of warheads and delivery systems are described. Some techniques for enhancing survivability will be examined relative to hardening aircraft and decreasing susceptibility to being acquired, tracked, and fired upon. Prereq: Basic Mechanics and Thermodynamics

SENG 565 - Control and State Space Concepts
This course covers topics in conventional and modern control theory. The interrelation between conventional and modern approaches is emphasized. Topics include: feedback systems analysis, root locus, Bode, and Nyquist analysis, state space feedback systems analysis, and control system compensation design. Prereq: Linear Systems Analysis - SENG 525 or equivalent.

SENG 581 - Survivability and Vulnerability of Systems
The fire control problem is introduced and various guidance laws are analyzed. Sensor and fuse functions are discussed. The analysis of weapon delivery errors is presented. Vulnerability analysis to non-nuclear threats, kill definitions and criteria, vulnerable areas and volumes, and relations to threat type are discussed. Susceptibility is defined and illustrated. Survivability enhancement techniques: reduction of observables, performance factors, hardening, etc., are presented. Design trade-offs and case studies are considered. Prereq: SENG 563

SENG 585 - Reliability in Systems Design
The purpose of this course is to introduce students to the probabilistic models and statistical methods used by reliability engineers. This first course gives basic definitions and terminology, investigates parametric lifetime models, non-parametric methods, and coherent systems analysis. Markov analysis techniques and an introduction to repairable system analysis. Emphasis will be placed on using these mathematical tools to models RAM as a dynamic process, develop test plans, perform graphical and statistical inference, as well as model product improvement the development process. Prereq: None

SENG 586 - Engineering Design for Reliability
Concepts of probability theory applied to fundamental design. Concentration on static design with introduction to techniques for dynamic systems. Topics include statistical tolerancing, interference theory, Monte Carolo analysis techniques, and various first order second moment methods. Methods for systems with time varying stress or strength characteristics will be introduced. Although emphasis is on structural/mechanical elements, application to other engineering fields will be presented. Prereq: STAT 601

SENG 590 - Aircraft Survivability
This course provides the student with an understanding of the essential elements in the study of survivability and system safety engineering of aerospace vehicles. Presented are technologies for increasing survivability and methodologies for assessing the probability of survival in hostile (non-

nuclear) environments. Air defense threat technology, identification of mission threat characteristics and threat operations are presented. Primary areas of study include identification, assessment and reduction of susceptibility and vulnerability and survivability enhancement of aerospace vehicles. Prereq: Undergraduate degree in engineering or science

SENG 620 - Topics in Systems Engineering
This course builds on the material presented in SENG 520, presenting additional depth and breadth in topics of use in systems engineering. Topics vary and have included system dynamics, chaos theory, general systems theory, and system architecting. Topics include, but are not limited to, multi-objective optimization, system design modeling languages, tradeoff and decision analysis, and design data management. Prereq: None

SENG 625 - Non-linear Systems Analysis and Control
This course serves as an introduction to the fundamental results of modern nonlinear control. The first half of the course will concentrate on the analytical tools that can be used to study a non-linear system. Specific topics in this area are phase-plane analysis, stability, and Lyapunov theory, perturbation methods and describing functions. The second half of the course will cover several nonlinear control synthesis techniques such as feedback linearization, sliding mode, and model reference adaptive control. Examples will be drawn from air and space applications. Prereq: Linear systems and state space control (SENG 525, 565 or equivalent).

SENG 631 - Spacecraft Systems Engineering
This course provides a detailed introduction to the design of complex space systems. The key elements and subsystems of several important classes of space systems are presented. The systematic approach necessary to effectively design space systems is illustrated through case studies. Individual or group design projects are conducted and presented. Prereq: SENG 520, MECH 532 and MECH 533 or Permission of Instructor

SENG 639 - Systems Design Project
This course provides a capstone system design experience for students who are not doing a systems design thesis. It will emphasize the practical details of applying systems engineering tools and techniques to a real multi-disciplinary design problem. Students will be assigned to small design teams and given a general problem statement. The team will be responsible for completing a thorough systems analysis of the problem, developing and evaluating alternative solutions, selecting the best alternative, proposing appropriate implementation of the selected solution, and documenting the entire experience. Students will also receive supplementary instruction covering details of the design process and new tools and techniques relevant to the selected projects. Prereq: SENG 520

SENG 640 - Systems Architecture
This course provides the foundations for developing and evaluating architectures for systems of systems. The process for generating a functional, physical and operational architecture from a top level operations concept will be developed. Both structured analysis and object oriented approaches to generating architectures will be discussed and applied to DOD concept problems. Generation of required DOD architecture products will be discussed. The course will also cover the generation of executable architecture models for evaluating the behavior of candidate system concepts. Prereq: SENG 520, CSCE 593.

SENG 665 - Multivariable Control Theory
This course covers the principles of linear multivariable control systems. Topics studied include the theory of full state and reduced order regulator and estimators. Multivariable Nyquist Stability Criteria,

LQG control theory, eigenstructure assignment theory, tracking control and an introduction to multivariable digital control analysis. Prereq: SENG 525 and SENG 565, or EENG 510 and EENG 562

SENG 685 - Reliability Engineering
This course is a continuation of SENG 585. This course introduces the students to some advanced reliability modeling and statistical analysis techniques. The student will be introduced to a variety of statistical inference procedures. Topics include sequential procedures, Bayesian procedures, and parameter estimation with covariates. Some of the specialized reliability models introduced in SENG 585 will be examined in more detail. In particular, competing risks, accelerated life, and proportional hazard models will be discussed. The final third of the course will focus on strategies currently being used to optimize the design of systems using the most cost effective combination of design parameters under uncertainty. Electrical circuits, mechanical structures, and manufacturing processes will be used as examples. Prereq: STAT 601 and SENG 585

SENG 687 - Advanced Topics in Reliability
The objective of this course is to introduce students to advanced topics in systems design in the area of reliability, maintainability, and availability applied to system design. Comparison of current Eastern/Western approaches to design is focus of course. Emphasis is on the application of design of experiments to improve quality of complex systems. Prereq: SENG 685, STAT 601 or Permission of Instructor

SENG 765 – Robust Control
This course covers robust control theory and applications. The emphasis is on a unified theory in which performance and robustness to plant uncertainties and/or input disturbances are handled directly. Modeling of uncertainty is covered, and signal and transfer function norms are used to quantify both the levels of uncertainty and robustness to it. Lyapunov and Riccati theory is treated in detail, as well as the concepts of parameterizing all stabilizing compensators, linear fractional transforms, linear matrix inequalities, and Hamiltonian matrices. The H2, H∞, μ-synthesis techniques are covered, and relevant examples from air and space systems will be used to demonstrate applications of these techniques. Prereq: SENG 565

SENG 766 – Current Topics in Robust Control
This is a very advanced course that follows the foundation laid in MECH 623. Continuing along the "post-modern" control theory approach, the basic ideas of H2 and H∞ optimization are expanded and refined. In particular, the course will cover such topics as: mixed objective optimal control (such as H2/H∞), μ-synthesis, l1 optimization, and direct reduced order control. The basic objective of this course is to update the student to the current state-of-the-art in linear control theory. Prereq: SENG 765

SENG 799 - Group Design Study
A design study on a topic of current Air Force interest (which may be classified) is selected as a class project. The class develops its own organizational structure to suit the problem, develops a statement of work and conducts the study. Progress reports and final reports are given to the sponsoring organization, as required. A formal written report is prepared by the group and accepted by the faculty in lieu of the Master's thesis. This course extends over 4 quarters and no credit is given until the end of the last quarter. Prereq: Enrolled in Systems Engineering Program

In addition, the following courses appear as requirements in the Systems Engineering Programs:

CSCE 593 - Introduction to Software Engineering
This course is concerned with the development of large-scale software programs. Techniques in requirements analysis, design, implementation, testing, and maintenance are presented, along with

discussions of the software development process. Several methodologies are discussed, including structured analysis (SA), objected oriented (OO) development, the Unified Modeling Language (UML), and the use of formal methods. Emphasis is on object-oriented modeling using a subset of the UML. Hands-on experience is provided through individual homework problems and a group project. Prereq: object-oriented program (CSCE 093 or equivalent)

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Appendix H: An Alternative Educational Model

AN ALTERNATIVE MODEL FOR ADVANCED DEGREES
Alexander H. Levis
Former Air Force Chief Scientist

An alternative model of how to provide quality education to a large number of Air Force personnel, especially those who are not selected for full time studies, is presented. This model is based on the concept of *lifelong learning* and not on degrees. Degrees do get obtained, but they are not the goal. They are obtained as recognition that a cycle of studies consisting of several "chunks" or modules taken over a period of time has been competed. It is a model that is closer to the PME model and is consistent with the educational trends in the last fifteen years where changes in technology and rapid changes in industry needs have forced scientists and engineers, regardless of what degrees they already have, to return to academia to take certificate programs on the new technologies and applications. This alternative model is not limited to systems engineering; it is suggested that systems engineering be the prototype for this approach.

The three premises of the approach are:

a.   Make available quality education where the Air Force people are,
b.   Provide education in increments that are consistent with the requirements of the AEFs and the PCS schedules and the needs of Air Force members, and
c.   Make AFIT have a *nationwide* presence - wherever the Air Force is.

The enabling concept for all the above is the *portability of academic credits*. At this time, almost all universities with quality programs have a residency requirement and limit the number of credits that a graduate student can transfer from another school. This is a serious handicap for all those who try to get Master's degrees as part time students but do no stay in one place long enough to obtain a degree. Consequently, some choose less desirable programs in specialties not relevant to the needs of the Air Force. The rotational schedule of the AEFs is going to make this problem more intractable.

The proposed approach is for AFIT to enter into agreements with selected universities in locations where Air Force personnel are stationed and who offer specific quality programs (e.g., in systems engineering) that are compatible with programs at AFIT. The courses can be offered at the university campuses or on bases by university faculty. AFIT will then cross-list the specific courses at the civilian university with the corresponding AFIT courses. A student that is admitted in the civilian university becomes also a "virtual" student at AFIT. When the student receives credit from the civilian university, he also receives credit at AFIT. The officer can then continue at another university where he accumulates more credits towards a degree at AFIT; he will probably not meet the new university's residence requirements for obtaining a degree there. Finally, the student goes for a quarter (3 months) or, at most, for two quarters (6 months) to AFIT to take the remaining AFIT courses for the degree - courses such as individual and team projects, labs, capstone courses, military applications courses. My understanding is that Commands are positively disposed to let one go on educational TDY for three months. Note that if a student stays long enough at a civilian university to earn that university's degree on a part time basis, he can do so.

AFIT needs to track these virtual students (not a difficult matter because many are processed through AFIT when they go to other universities); it will be the keeper of the portable credits. The AFIT curricula would become more focused to the needs of the Air Force as fewer resources would need to be expended

on teaching standard material available everywhere. AFIT will also has a much larger number of students for its advanced courses that are particularly relevant to the Air Force and that civilian universities do not provide (e.g., C2, information warfare, information assurance, weapons systems, etc.).

The matter has been discussed informally with several universities and the response has been positive. It is a win-win situation. The universities reserve their usual right to select whom they admit. They gain by populating their classes with additional qualified students and receiving the appropriate tuition payments. The Air Force personnel receive the best education for which they qualify at their location and do not loose the credits when they move to another base. These portable credits are created and are managed by AFIT They also attend AFIT for a short period to receive Air Force specific education. Another advantage is that AFIT can set its own requirements regarding length of time allowed to earn a degree. Students can take modules at different universities and obtain certificates. Two or three such modules may qualify a person for the advanced degree.

This model was submitted to Generals Cook, Lord, and Lyles and to Mrs. Natalie Crawford for their review. Their constructive comments and suggestions were much appreciated and have been incorporated. Assistant Secretary Mike Dominguez has also reviewed this model and called a meeting with DP (Roger Blanchard, MGen Speigel, Bill Kelly, BGen Hassan and several others) to examine the approach and consider its implementation. I look forward to working with DP to see if there is a way that these concepts can be implemented as part of the broader Force Development construct. A cultural change at AFIT would also be required to implement the nationwide aspect.

One area that is very relevant to this model but is not addressed here is distance learning. This will be an increasingly important contributor to the education of Air Force personnel in the future. However, I need to do some more homework and also work closely with AETC before having some actionable recommendations to present.[1]

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[1] In early 2004 a pilot project on distance learning was initiated with sponsorship by the AETC Commander, General Cook. Project HERMES was executed by AFRL/HE (at Brooks) and the Air Force Institute for Advanced Distance Learning (AFIADL) at Maxwell AFB. It was briefed at CORONA Top in June 2004.

Appendix I: INCOSE Directory of Systems Engineering Academic Programs

The following list of academic institutions located worldwide offer a diverse mix of bachelors, masters, and doctoral level programs in systems engineering and systems engineering management. This list reflects the efforts of the Education and Research Technical Committee and is continuously being updated.

Air Force Institute of Technology, Dayton, OH, US

Ajou University / Institute for Advanced Engineering in Korea, Korea

Arizona State University, Tempe, AZ, US

Auburn University, Auburn, AL, US

Boston University, Boston, MA, US

California State University - Fullerton, Fullerton, CA, US

Carleton University, Ontario, Canada

Case Western Reserve University, Cleveland, OH, US

Colorado School of Mines, Golden, CO, US

Colorado State University - Pueblo, Pueblo, CO, US

Colorado Technical University, CO, US

Cornell University, Ithaca, NY, US

Cranfield University / Royal Military College of Science, Swindon, Wiltshire, England

Delft University of Technology, Delft, The Netherlands

École des Hautes Études Commerciales, Montréal, Canada

Elmhurst College, Elmhurst, IL, US

Embry Riddle Aeronautical University, Daytona Beach, FL, US

Essex University, Colchester, Essex, England

Florida Institute of Technology, Melbourne, FL, US

George Mason University, Fairfax, VA, US

George Washington University, Washington, DC, US

Georgia College and State University, Milledgeville, GA, US

Georgia Institute of Technology, Atlanta, GA, US

Huazhong University of Science &Technology (HUST), China

Indian Institute of Technology- Bombay; Aerospace Engineering, India

International Space University, Illkirch, Graffenstanden, France

Iowa State University, Ames, IA, US

Johns Hopkins University, Baltimore, MD, US

Kansas State University, KS, US

Long Island University-C W Post Campus, Brookville, NY, US

Loughborough University, Loughborough, Leics, England

Louisiana Tech University, Ruston, LA, US

Maine Maritime Academy, Castine, ME, US

Massachusetts Institute of Technology, Cambridge, MA, US

Michigan State University, East Lansing, MI, US

Military Institute of Engineering of Brazil, Brazil

National Technological University Corp., Fort Collins, CO, US

Naval Post Graduate School, Monterey, CA, US

New Jersey Institute of Technology, Newark, NJ, US

North Carolina A&T University, Greensboro, NC, US

Northeastern University, Boston, MA, US

Oakland University, Rochester, MI, US

Ohio State University, Columbus, OH, US

Ohio University, Athens, OH, US

Old Dominion University, Norfolk, VA, US

Pennsylvania State University, University Park, PA, US

Penn State University at Great Valley, Malvern, PA, US

Polytechnic University, Brooklyn, NY, US

Polytechnic University - Farmingdale, Farmingdale, NY, US

Portland State University, Portland, OR, US

Purdue University, West Lafayette, IN, US

Rensselear Polytechnic University, Troy, NY, US

Rochester Institute of Technology, Rochester, NY, US

Royal Melbourne Institute of Technology University, Melbourne, Australia

Rutgers, The State University, Piscataway, NJ, US

San Jose State University, San Jose, CA, US

Southern Methodist University, Dallas, TX, US

Stanford University, Stanford, CA, US

Stevens Institute of Technology, Hoboken, NJ, US

Texas Tech University, Lubbock, TX, US

University College London, London, England

University of Alabama, Huntsville, Huntsville, AL, US

University of Alberta, Edmonton, Canada

University of Arizona, Tucson, AZ, US

University of Central Florida, Orlando, FL, US

University of Connecticut, Storrs, CO, US

University of Florida, Gainesville, FL, US

University of Hertfordshire, England

University of Houston, Houston, TX, US

University of Houston - Clear Lake, Houston, TX, US

University of Idaho, Idaho Falls, ID, US

University of Illinois, Urbana, IL, US

University of Maryland, College Park, Maryland, MD, US

University of Massachusetts, Boston, MA, US

University of Memphis, Memphis, TN, US

University of Michigan Ann Arbor, Ann Arbor, MI, US

University of Michigan-Dearborn, Dearborn, MI, US

University of Minnesota, Minneapolis, MN, US

University of Missouri-Rolla, Rolla, MO, US

University of Pennsylvania, Philadelphia, PA, US

University of Pittsburgh, Pittsburgh, PA, US

University of Regina, Regina, SK, CA

University of Rhode Island, Kingston, RI, US

University of Sheffield, Sheffeld, England

University of South Australia, South Australia, Australia

University of South Florida, Tampa, FL, US

University of Southern California, Los Angeles, CA, US

University of St. Thomas, St. Paul, MN, US

University of Virginia, Charlottesville, VA, US

University of Waterloo, Ontario, Canada

Virginia Polytechnic and State University, Blacksburg, VA, US

Washington University, WA, US

Wichita State University, Wichita, KS, US

Youngstown State University, OH, US

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Appendix J: The AFIT Masters Degree Program in Systems Engineering

The following program description was taken directly from the AFIT web site (See
http://en.afit.edu/ENY/DegreeProgs/gse.cfm)

The Graduate Systems Engineering (GSE) program is an ABET accredited resident program at AFIT leading to a Master of Science (MS) degree in Systems Engineering. It is nominally a six quarter (18 month) program, with students normally entering in September and graduating in March. The Systems Engineering program provides a substantial technical foundation in systems architecture, analysis and design as well as opportunity for specialization within a traditional engineering discipline. Students with non-technical backgrounds may be admitted into the program, but may require preparatory math and other courses in addition to the Systems Engineering program requirements. The program culminates with an individual thesis or group design project typical of a defense system project. In the design study, the student will apply their individual technical expertise, exercise their system design skills, and experience the group dynamics of a team design effort while solving a realistic defense system problem. Finally, the program provides the necessary education to qualify full-time quota students for the academic degree code assigned to them on entry into the program.

Program Educational Objectives

The SE program takes students with traditional engineering backgrounds (mechanical, electrical, aerospace, etc.) and produces graduates who can effectively use the tools and techniques of both systems science and traditional engineering disciplines to approach and analyze complex problems, design feasible solutions, and select an appropriate solution. Specific objectives are as follows:

1. A graduate will understand the role of a Systems Engineer, both as it applies to the government organization as well as their counterparts in industry.
2. A graduate will have a thorough understanding of the Systems Engineering process, from mission area analysis through requirements definition and system development, sustainment and retirement.
3. The graduate will have the base knowledge to become proficient with many of the tools for implementing the SE process, to include development of system architectures, tradeoff and decision analysis, risk management and test planning.
4. The graduate will have the skills to effectively participate in the evaluation of both competing designs as well as proposed processes from competing contractors.
5. The student will develop a detailed understanding in at least one technical specialty area.

Program Elements

The GSE program curriculum has the following components:

1. core courses
2. a mathematics or math science requirement
3. a distribution requirement
4. engineering depth to include an applicable education code sequence
5. an individual thesis or group project
6. any additional Air Force and/or ABET requirements.

The graduation requirements are 48 quarter hours (minimum) covering the program elements as discussed next.

Core Courses: The systems engineering core courses comprise:

- systems engineering management (SENG 510)
- systems engineering design (SENG 520)
- introduction to software engineering (CSCE 593)
- system architecture (SENG 640).

These courses provide a common breadth of knowledge and the basic building blocks for all Air Force and DOD systems engineers. All core courses are 4 quarter hours.

Mathematics Requirement: Students must complete at least one course in graduate mathematics or math science. Students without a background course in probability and statistics will take a math course in this area. Students with an operations research education code, or those taking a stochastic systems concentration, should consider the more theoretical probability and statistics courses (STAT 527/537). Appropriate math science courses include:

- linear systems (SENG 525)
- deterministic or probabilistic operations research (OPER 510/540)
- decision analysis (OPER 543), or design optimization (MECH 620).

The mathematics or math science courses are 3-4 quarter hours.

Distribution Requirement: The distribution requirement includes a course in project management and/or human factors. Appropriate courses include:

- cost management (AMGT 600)
- project risk analysis (QMGT 680)
- cost analysis for system design (OPER 632)
- engineering economics (ENVR 580)
- human-computer interaction (IMGT 663).

The distribution courses are 3-4 quarter hours.

Engineering Depth: Systems engineering students will also take appropriate engineering and/or applied science courses in the technology area of their thesis or group design project as recommended by their program and/or thesis advisor. While the number of courses in the engineering sequence may vary, it is typically three or more courses for 12 or more quarter hours of credit. Candidate sequences will be developed by the student and the academic advisor and approved by the curriculum chair. A candidate sequence should be a cohesive group of classes in a single discipline area with at least one 600-leel (or above) course. Candidate sequences include but are not limited to:

Individual Thesis or Group Project: The capstone of the AFIT systems engineering program is the group design project. The students typically form a systems engineering team and perform a group design study, which is defended orally. However, in certain situations, such as exists for part-time students or single-student classes, an individual thesis may be performed. In any case, the team or individual works on a major project of Air Force interest allowing the students to apply the systems approach to a real problem in a controlled environment. Some recently completed studies have been:

- "Integrating Automated Multi-Disciplinary Optimization in Preliminary Design of Non-traditional Aircraft"
- "Development of an Active Anti-missile Defense System for the C/KC-135 Aircraft"
- "Prototype Space Fabrication Platform," "System Study of the KC-10 Aerial Refueling System"
- "Design of Integrated Satellite Power Storage and Attitude Control Using Flywheels."

The thesis project for the GSE program will be 12 quarter hours, typically spread over 3 or more quarters.

AF and ABET Requirements

The degree requirements for the GSE program is 48 quarter hours; additional coursework (technical electives) may be required beyond the program elements discussed above in order to total 48 hours or to meet other prerequisites. In addition, all full-time Air Force students typically complete an average of twelve credits per quarter for a minimum of 72 total credits during the normal 6-quarter resident program.

Any student not meeting ABET requirements from their undergraduate program is expected to take courses to fulfill those requirements as part of their MS program. An individual assessment of the student's transcript will be made as part of the education plan development process when the student enters AFIT. At this time, the student will be notified of any additional courses required for ABET accreditation. The student's advisor will be responsible for verifying that the program contains sufficient engineering design courses to satisfy ABET requirements. This includes the requirement to take four engineering design courses. Students who cannot satisfy all ABET requirements for the Master of Science in Systems Engineering, usually due to a non-ABET undergraduate degree, will be awarded the Master of Science degree accredited by the North Central Association of Colleges and Schools.

Air Force officers attending AFIT as full-time quota students are assigned an Advanced Academic Degree Code, or education code. Currently supported education codes and their corresponding requirements are listed below. The required courses may be taken as part of, or in addition to, the engineering depth sequence mentioned above.

Graduate Certificate Program

AFIT now offers a Graduate Certificate Program (SEC) in Systems Engineering that consists of 4 required core courses:

1. SE Process and Requirements Driven Design (SENG 520)
2. Introduction to Software Engineering (CSCE 593)
3. Systems Architecture (SENG 640)
4. SE Management (SENG 510).

Additionally, it includes an SE Capstone Group Project (SENG 699). These courses are part of the Master of Science (MS) degree program and may also be used towards that degree or a minor concentration in another AFIT degree program.

Sample Program (4TYY with Systems and Control Emphasis)

Short-term review (4 weeks): Computers, Dynamics, Mathematics

1st Quarter (Fall)

- SENG 520 – Systems Engineering Process and Design (4 credits)
- SENG 525 – Linear Systems (4 credits)
- Tech electives (8 credits)

2nd Quarter (Winter)
- MECH 529 – Dynamics and Control (4 credits)
- SENG 565 – Control and State Space Concepts (4 credits)
- CSCE 593 – Intro to Software Engineering (4 credits)
- Tech electives (4 credits)

3rd Quarter (Spring)
- Distribution Course of Tech Elective (4 credits)
- SENG 640 – Systems Architecture
- Tech electives (4 credits)

4th Quarter (Summer)
- SENG 510 – Systems Engineering Management (4 credits)
- SENG 625 – Nonlinear Systems Analysis and Control (4 credits)
- Thesis (4 credits)

5th and 6th Quarters (Fall, Winter)
- Thesis (4 credits)
- Tech electives (4 credits)

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ABSTRACT (Maximum 200 Words) *Academic Audit of AFIT Programs in Systems Engineering:* This report provides an assessment and recommendations for the systems engineering educational programs at the Air Force Institute of Technology (AFIT). The Air Force needs in systems engineering education are briefly summarized, followed by an analysis of the educational program at AFIT. Based on the assessment of AFIT's program, a set of recommendations are given for improving the programs and their utility to the Air Force. Appendices to the report contain additional information on the AFIT programs and an assessment of other graduate systems engineering programs in the US.			
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